



the **ENERGY** lab

PROJECT FACTS

Carbon Storage – RCSP

Plains CO₂ Reduction Partnership— Development Phase Large-Scale Field Projects

Background

The U.S. Department of Energy Regional Carbon Sequestration Partnership (RCSP) Initiative consists of seven partnerships. The purpose of these partnerships is to determine the best regional approaches for permanently storing carbon dioxide (CO₂) in geologic formations. Each RCSP includes stakeholders comprised of state and local agencies, private companies, electric utilities, universities, and nonprofit organizations. These partnerships are the core of a nationwide network helping to establish the most suitable technologies, regulations, and infrastructure needs for carbon storage. The partnerships include more than 400 distinct organizations, spanning 43 states and four Canadian provinces, and are developing the framework needed to validate geologic carbon storage technologies. The RCSPs are unique in that each one is determining which of the numerous geologic carbon storage approaches are best suited for their specific regions of the country and are also identifying regulatory and infrastructure requirements needed for future commercial deployment. The RCSP Initiative is being implemented in three phases, the Characterization Phase, Validation Phase, and Development Phase. In September 2003, the Characterization Phase began with the seven partnerships working to determine the locations of CO₂ sources and to assess suitable locations for CO₂ storage. The Validation Phase (2005–2012) focused on evaluating promising CO₂ storage opportunities through a series of small scale field projects in the seven partnership regions. Finally, the Development Phase (2008–2020+) activities are proceeding and will continue evaluating how CO₂ capture, transportation, injection, and storage can be achieved safely, permanently, and economically at large scales. These field projects are providing tremendous insight regarding injectivity, capacity, and containment of CO₂ in the various geologic formations identified by the partnerships. Results and assessments from these efforts will assist commercialization efforts for future carbon storage projects in North America.

The Plains CO₂ Reduction (PCOR) Partnership, led by the University of North Dakota's Energy & Environmental Research Center (EERC), includes all or part of the states of Iowa, Minnesota, Missouri, Montana, Nebraska, North Dakota, South Dakota, Wisconsin, and

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U.S. DEPARTMENT OF
ENERGY

PARTNERS (2003 TO PRESENT)

Abengoa Bioenergy New Technology, Inc.
Air Products and Chemicals, Inc.
Alberta Department of Energy
Alberta Department of Environment
Alberta Innovates - Technology Futures
ALLETE
Ameren Corporation
American Coalition for Clean Coal Electricity
American Lignite Energy
Apache Canada Ltd.
Baker Hughes Incorporated
Basin Electric Power Cooperative
Bechtel Corporation
Biorecro AB
Blue Source, LLC
BNI Coal, Ltd.
British Columbia Ministry of Energy, Mines, and Petroleum Resources
British Columbia Oil and Gas Commission
C12 Energy, Inc.
Chicago Climate Exchange
Computer Modelling Group, Inc.
Dakota Gasification Company
Denbury Onshore LLC
Ducks Unlimited Canada
Ducks Unlimited, Inc.
Eagle Operating, Inc.
Eastern Iowa Community College District
Enbridge Inc.
Encore Acquisition Company
Energy & Environmental Research Center (University of North Dakota)
Energy Resources Conservation Board/ Alberta Geological Survey
Environment Canada
Excelsior Energy Inc.
Great Northern Project Development, LP
Great River Energy

Wyoming and the Canadian provinces of Alberta, British Columbia, Manitoba, and Saskatchewan. The PCOR Partnership has received support from more than 100 organizations. The nine states in the PCOR Partnership account for about 11 percent of total U.S. CO₂ emissions from stationary sources. Regional characterization activities conducted by the PCOR Partnership confirmed that while numerous large stationary CO₂ sources are present, the region also has tremendous potential for CO₂ storage. The varying natures of the sources and storage sites reflect the geographic and socioeconomic diversity across this nearly 1.4 million mi² area of central North America. The region offers significant potential for storage in deep saline formations (both carbonate and clastic formations), unmineable coal seams, and depleted oil and natural gas fields. Of particular interest to this region of the U.S. is the optimization of CO₂ for geologic storage in tandem with enhanced oil recovery (EOR).

Project Description

Project Summary

The PCOR Partnership is planning two large-scale CO₂ projects (Bell Creek site and Fort Nelson site) for the Development Phase, also known as Phase III (Figure 1).

Bell Creek Site

For the Bell Creek large-scale project, the PCOR Partnership is working with Denbury Onshore LLC (Denbury) to develop robust, practical, and targeted support programs to study incidental CO₂ storage associated with a commercial-scale EOR operation. These programs include modeling and simulation; monitoring, verification, accounting (MVA), and assessment;



Project locations for the two PCOR Partnership Development Phase Projects

and risk management programs of appropriate size for a commercial-scale injection of CO₂. The project is being conducted in the Bell Creek Oil Field in Powder River County in southeastern Montana, and will provide insight into the relationship between successful incidental CO₂ storage and tertiary recovery on oil production within a sandstone reservoir in the Cretaceous Muddy Formation. The Bell Creek project is a significant opportunity to develop a set of cost-effective MVA protocols for large-scale CO₂ storage associated with a commercial-scale EOR operation.

Fort Nelson Site

The Fort Nelson Carbon Capture and Storage (CCS) Feasibility Project, an international collaboration led by Spectra Energy that includes industry, government, universities, and technologists, has initiated what may ultimately be the largest application of deep saline geologic storage in the world. If proven feasible, this project will provide permanent storage of up to 2 million metric tons of CO₂ per year from the Fort Nelson gas processing facility, the largest processing facility in the region and the largest of its type in North America. The concept of the project is to capture sour CO₂ (mixture of CO₂ and hydrogen sulfide [H₂S]) from one of the largest gas-processing plants in North America and inject it into a deep saline formation. The sour CO₂ will be compressed and transported approximately 9 miles (15 kilometers) in a supercritical state via pipeline to the target injection location. The target zone will be a carbonate rock (limestone and dolomite) formation in the Devonian-age Elk Point Group. The injection location will be in relatively close proximity to the gas plant at a depth of >7,200 feet.

Injection Site Description

Bell Creek Site

The specific host site for the injection wells for the Bell Creek demonstration is located in the Bell Creek Oil Field approximately 30 miles southeast of Broadus, Montana.



Drilling an exploratory well in the Ft. Nelson Area

PARTNERS (CONT.)

Halliburton
Hess Corporation
Huntsman Corporation
Husky Energy Inc.
Indian Land Tenure Foundation
Interstate Oil and Gas Compact Commission
Iowa Department of Natural Resources – Geological Survey
Kiewit Mining Group
Lignite Energy Council
Manitoba Geological Survey
Manitoba Hydro
Marathon Oil Company
MEG Energy Corporation
Melzer Consulting
Minnesota Pollution Control Agency
Minnesota Power
Minnkota Power Cooperative, Inc.
Missouri Department of Natural Resources
Missouri River Energy Services
Montana Department of Environmental Quality
Montana-Dakota Utilities Company
Montana Public Service Commission
Murex Corporation
National Commission on Energy Policy
Natural Resources Canada
Nebraska Public Power District
Nexant, Inc.
North American Coal Corporation
North Dakota Department of Commerce
Division of Community Services
North Dakota Department of Health
North Dakota Geological Survey
North Dakota Industrial Commission
Department of Mineral Resources, Oil and Gas Division
North Dakota Industrial Commission
Lignite Research, Development and Marketing Program
North Dakota Industrial Commission Oil and Gas Research Council

PARTNERS (CONT.)

North Dakota Natural Resources Trust
North Dakota Petroleum Council
North Dakota Pipeline Authority
North Dakota State University
Otter Tail Power Company
Oxand Risk & Project Management Solutions
Petroleum Technology Research Centre
Petroleum Technology Transfer Council
Pinnacle, a Halliburton Service
Prairie Public Broadcasting
Pratt & Whitney Rocketdyne, Inc.
Praxair
Ramgen Power Systems, Inc.
RPS Energy Canada Ltd
Saskatchewan Ministry of Energy and Resources
SaskPower
Schlumberger Carbon Services
Shell Canada Energy
Spectra Energy
Strategic West Energy Ltd.
Suncor Energy Inc.
TAQA North Ltd.
Tesoro Refinery (Mandan)
TGS Geological Products and Services
U.S. Department of Energy
U.S. Geological Survey Northern Prairie Wildlife Research Center
University of Alberta
University of North Dakota
University of Regina
Weatherford Advanced Geotechnology
Western Governors' Association
Westmoreland Coal Company
WBI Energy, Inc.
Wisconsin Department of Agriculture, Trade, and Consumer Protection
Wyoming Office of State Lands and Investments
Xcel Energy

Fort Nelson Site

The specific host site for the injection wells for the Fort Nelson demonstration will be located in northeastern British Columbia, approximately 9 miles west of the Fort Nelson gas plant (Figure 2).

Description of Geology

Bell Creek Site

CO₂ is being injected into the oil-bearing sandstone reservoir in the Lower Cretaceous Muddy (Newcastle) Formation at a depth of approximately 4500 feet. Within the Bell Creek oil field, the Muddy Formation is dominated by high-porosity (25%–35%), high-permeability (150–1175 mD) sandstones deposited in a nearshore marine environment. The initial reservoir pressure was approximately 1200 psi, which is significantly lower than the regional hydrostatic pressure regime (2100 psi at 4500 ft) which provides evidence of effective seals above and below the reservoir. The oil field is located structurally on a shallow monocline with a 1°–2° dip to the northwest and with an axis trending southwest to northeast for a distance of approximately 20 miles. Stratigraphically, the Muddy Formation in the Bell Creek oil field features an updip sand facies pinchout into shale facies serving as a trap. The barrier bar sand bodies of the Muddy Formation strike southwest to northeast and lie on a regional structural high, which represents a local paleodrainage deposition. A deltaic siltstone overlaps the sandstone on an erosional barrier bar surface and, finally, is partially dissected and somewhat compartmentalized by intersecting shale-filled incisive erosional channels. The overlying Lower Cretaceous Mowry Shale provides the primary seal, preventing fluid migration to overlying aquifers and to the surface. On top of the Mowry Shale are several thousand feet of low-permeability formations, including the Belle Fourche, Greenhorn, Niobrara, and Pierre Shales, which will provide redundant layers of protection in the unlikely event that the primary seal fails to prevent upward fluid migration fieldwide.

Fort Nelson Site

The target zone for the Fort Nelson injection is a carbonate rock formation, known as the Elk Point Group, located at a depth of >7,200 feet. The Elk Point Group is composed of carbonate rocks with average porosities ranging from 8% to 12%, with permeability in the tens to hundreds of millidarcies range. These rocks were deposited in a series of reef-building events and have undergone extensive post-depositional alteration, resulting in a highly heterogeneous mixture of dolomites and limestones. Although highly variable in geology, formations within the Elk Point Group have held large natural gas fields locally and regionally, demonstrating their ability to hold large quantities of gas for geologic time periods. Thick, competent, laterally continuous shales of the Devonian Fort Simpson and Muskwa Formations act as the primary confining zone holding this gas in place and will also act as the primary confining zone for CO₂ storage. These shales range in thickness between 1,310 and 1,970 feet in the Fort Nelson area and are characterized by low permeability and high geomechanical strength, and should make excellent seals for CO₂ storage. Secondary confinement also exists above the Fort Simpson Formation, the most competent and massive being the Banff Formation, which is predominantly shale and is not less than 100 feet thick in the Fort Nelson area.

Source of CO₂

Bell Creek Site

Carbon dioxide for the Bell Creek demonstration is being sourced from ConocoPhillips' Lost Cabin Gas Plant, a gas-processing facility located in Fremont County, Wyoming. The Lost Cabin Gas Plant currently supplies approximately 50 million cubic feet of CO₂ per day to the Bell Creek oil field. Denbury and Conoco Phillips have entered into a CO₂ purchase-and-sale agreement, and compression facilities adjacent to the Lost Cabin Gas Plant pressurize the CO₂ from approximately 50 to 2,200 psi, for transportation to the project site at a near-injection-ready pressure. This infrastructure includes a 232-mile pipeline that was completed in 2012 that is bringing CO₂ to the injection site at a rate of approximately 1 million metric tons per year (Figure 3). Denbury commercial activities are estimated to recover approximately 30 million bbl of incremental oil over the operation's 20- to 25-year life, but these commercial activities are outside the scope of the PCOR Partnership project.

Fort Nelson Site

The Fort Nelson demonstration will utilize sour CO₂ from the Spectra Energy Fort Nelson Natural Gas-Processing Plant in northwestern British Columbia, Canada. The sour CO₂ will be captured using an existing amine-based acid gas removal system, dried, compressed, and transported by pipeline as a supercritical fluid to a nearby injection site. Its composition will be approximately 95 percent CO₂ and 5 percent H₂S.

Injection Operations

Bell Creek Site

The injection strategy for Bell Creek was developed by Denbury, for the purposes of commercial CO₂ EOR. Note that Denbury's commercial CO₂ EOR operations are independent for the PCOR research project. Under PCOR, the EERC is conducting site characterization, modeling and predictive simulation, and MVA to study the interrelationship of commercial CO₂ EOR and incidental CO₂ storage and to evaluate how various EOR injection strategies affect reservoir response, storage efficiencies, and storage capacities. Injection in the Bell Creek oil field began in May 2013. Since the Bell Creek Oil Field has undergone secondary recovery, much of the infrastructure necessary for a combined CO₂ EOR and CO₂ storage project was already in place. In addition, Denbury has constructed a 232-mile CO₂ pipeline (known as the Greencore Pipeline) which is delivering CO₂ from the ConocoPhillips Lost Cabin gas-processing plant to the Bell Creek Oil Field. The pipeline was completed in November 2012. Surface facilities and support infrastructure were constructed, and were commissioned in August 2013. These facilities allow for CO₂ separation from produced hydrocarbons and subsequent reinjection into the Muddy Formation

PROJECT DURATION

Start Date

10/01/2007

End Date

09/30/2017

COST

Total Project Value

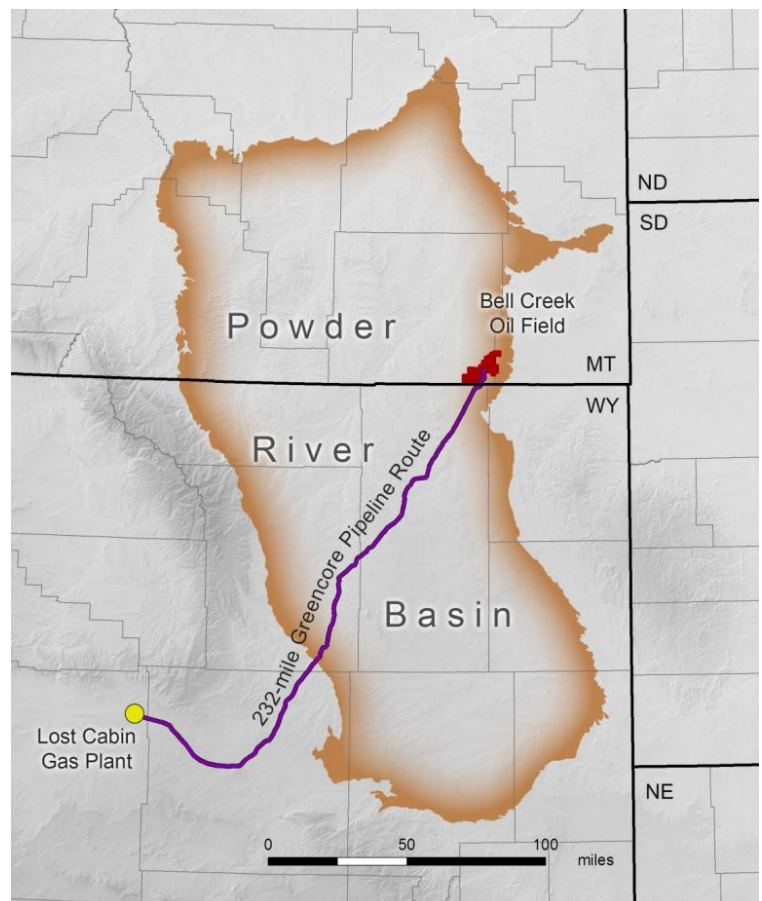
\$111.887,927

DOE/Non-DOE Share

\$73,277,718 / \$38.610,209

PROJECT NUMBER

FC26-05NT42592



Location of the Lost Cabin Gas Plant and Greencore Pipeline.

at a depth of approximately 4,500 feet and a temperature of 110°F. These pressures and temperatures will ensure that the CO₂ remains in a supercritical state in the reservoir. Currently planned operations consist of a continuous CO₂ flood followed by a water alternating gas (WAG) cycle utilizing both recycled CO₂ from the processing facilities and incoming CO₂ from the Greencore Pipeline.

Fort Nelson Site

For the Fort Nelson demonstration, if proven feasible, Spectra Energy will install significant infrastructure to transport the supercritical sour CO₂ to the injection site, including construction of compressors, a dehydration system, a pipeline for the sour CO₂ gas stream, and a pump. The target injection formation is at a depth of >7,200 feet. Formations in this depth range will be at temperatures and pressures that ensure the injected sour CO₂ remains in a supercritical state.

Simulation and Monitoring of CO₂

In the Development Phase, an emphasis has been placed on developing practical, site-specific, cost-effective, and risk-based MVA plans. This philosophy begins with a thorough site characterization, which is used to develop geologic models and perform injection simulations to predict the long-term fate of the injected CO₂. Both the site characterization and the modeling and simulation then feed into a detailed and iterative risk assessment process which is used to identify potential leakage and migration risks, from which a detailed, site-specific, risk-based MVA plan is developed. This integrated approach will be repeated throughout the course of the project, and the cycle can be repeated and at any point if more data are required.

Goals and Objectives

The primary objective of the DOE's Carbon Storage Program is to develop technologies to safely and permanently store CO₂ and reduce greenhouse gas emissions without adversely affecting energy use or hindering economic growth. The programmatic goals of Carbon Storage research are to (1) develop and validate technologies to ensure 99 percent storage permanence; (2) develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness; (3) support industry's ability to predict CO₂ storage capacity in geologic formations to within 30 percent; and (4) develop Best Practices Manuals (BPMs) for monitoring, verification, accounting, and assessment; site screening, selection, and initial characterization; public outreach, well management activities, and risk analysis and simulation.

The PCOR Partnership's overall goal is to validate the information and technology developed under the Characterization and Validation Phases relative to research and field activities, public outreach efforts, and regional characterization. Specific objectives include the following:

- Conduct a successful Bell Creek large-scale injection to verify and validate the concept of utilizing the region's many oil fields for large-scale injection of anthropogenic CO₂, resulting safe long-term storage of CO₂ while producing incremental oil volumes.
- Conduct a successful Fort Nelson large-scale feasibility study and to ultimately provide risk management and MVA support for the injection to verify and validate the concept of utilizing the region's carbonate saline formations for large-scale injection and storage of anthropogenic CO₂.
- Establish MVA methods to safely and effectively monitor commercial-scale simultaneous CO₂ EOR and CO₂ storage projects.
- Utilize the commercial practices as the backbone of the MVA strategy and augment with additional cost-effective techniques.
- Share lessons learned for the benefit of similar projects across the region.
- Establish the relationship between the CO₂ EOR process and long-term storage of CO₂.
- Verify and validate the technical and economic feasibility of using brine-saturated carbonate formations for large-scale CO₂ injection.
- Gather characterization data that will verify the ability of the target formations to meet the goal of storing 50 percent of the region's point source CO₂ emissions for the next 100 years.
- Advance the regulatory and permitting framework.
- Demonstrate that robust MVA of a brine-saturated CO₂ storage project can be conducted cost-effectively.
- Develop methods to provide the technical information needed to monetize carbon credits for CO₂ stored in geologic formations.
- Meet or exceed the expectations of the members of the PCOR Partnership by developing project(s) that are commercially successful.

Accomplishments to Date

- Injection of CO₂ began in May 2013.
- Completed surface and near surface baseline monitoring.
- Completed drilling, coring, logging, and installation of permanent downhole monitoring equipment on a dedicated monitoring well.
- Drilled and completed two deep groundwater-monitoring wells in the lowermost USDW.
- Collected high resolution log data and geologic core on two additional characterization wells.
- Installed soil gas profile stations.
- Began passive seismic monitoring.
- Completed baseline 3-D vertical seismic profile surveys, 3-D surface seismic survey, and pulsed-neutron log campaign.
- Completed update of geocellular model and associated history matching and predictive simulations utilizing newly collected data from characterization and baseline MVA activities
- Completed technical risk assessment.

Fort Nelson

- Completed drilling, coring, and logging of the stratigraphic well at the Fort Nelson site.
- Acquired existing 2-D and 3-D seismic data in the area of the Fort Nelson site.
- Completed two rounds of modeling and risk assessments for the Fort Nelson site.
- The Fort Nelson CCS Project was recognized by the Carbon Sequestration Leadership Forum (CSLF) at its London Ministerial meeting held in October 2009.

PCOR Programmatic Accomplishments

- Conducted second round of PCOR Partnership programmatic risk assessment.
- Outreach products have received multiple awards. For example, "Reducing Our Carbon Footprint: The Role of Markets", which was an original 30-minute feature production providing information on anthropogenic CO₂ emissions, received a Communicator Award of Excellence.

"Out of the Air-Into the Soil: Land Practices that Reduce Atmospheric Carbon", another original 30-minute feature production received a Communicator Award of Excellence and a Gold Aurora Award. "Global Energy and Carbon: Tracking Our Footprint," the EERC's fifth 30-minute production, received a Platinum Best of Show Aurora Award.

Benefits

The PCOR Partnership region, which covers over 1.4 million square miles, emits approximately 562 million metric tons of CO₂ yearly from large stationary sources in the region. Research through the PCOR Partnership Development Phase projects can be used to ensure that geologic storage is not just an option for the distant future, but can be implemented on a large scale for both environmental and commercial reasons. Overall, based on the current geological formations characterized, the PCOR Partnership region has the storage resource of 313 billion metric tons of CO₂ in saline formations, 3.2 billion metric tons in depleted oil fields, and 7.3 billion metric tons in unmineable coal seams, which is over four times the anticipated regional emissions over the next 100 years, assuming a static emission profile.

The integrated approach at the Bell Creek Oil Field helps meet the commonsense safety expectations of local landowners and communities. Further, by storing anthropogenic CO₂ at the Bell Creek Oil Field, Denbury benefits the environment by offsetting the carbon footprint of its regional oil field operation. The results of the Bell Creek project will help future projects effectively implement a proven CO₂ MVA system as part of a comprehensive approach to subsurface CO₂ management, utilizing it for regional EOR operations.

While providing a substantial reduction in CO₂ emissions, the Fort Nelson project will also facilitate the development of significant shale gas reserves in the Horn River Basin to provide North American markets with clean natural gas. Research aspects of the effort are being designed to provide proof of concept for geologic CO₂ storage in deep saline formations, particularly for co-storage with sour gas, and serve as a model for follow-on CCS projects using geologic CO₂ management at other gas-processing facilities in the region and around the world.



